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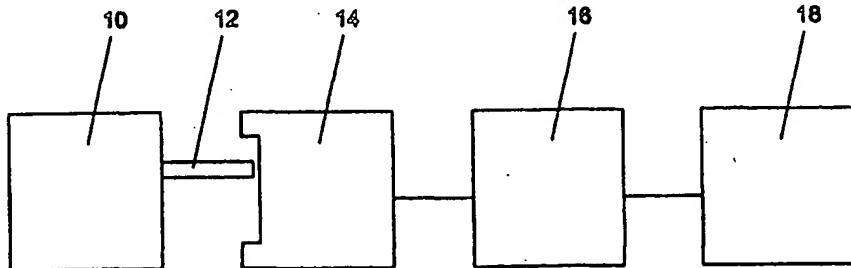
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(54) Title: CONTROL APPARATUS



(57) Abstract

Control apparatus comprising at least one electrically-conductive target portion (12). A position sensor (14) in the form of a pulse induction device is arranged in proximity with the said at least one electrically-conductive portion (12) to provide a signal indicative of a position attribute of that portion. Relative movement is possible between the target portion (12) and a coil portion (14a) of the position sensor (14). Control means (16) are connected to receive such a signal from the pulse induction device (14) and to respond in dependence upon that signal. The invention extends to such a position sensor (14) itself.

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**C ntrol apparatus**

The present invention relates to control apparatus comprising at least one electrically-conductive target portion, and a position sensor in the form of an induction device arranged in proximity with the said at least one electrically-conductive target portion to provide a signal indicative of an attribute of the position of that portion relative to a portion of the induction device, and control means connected to receive such a signal from the induction device and to respond in dependence upon that signal.

Hitherto, the induction device has comprised a linear variable differential transformer (commonly abbreviated as an LVDT). Such a device comprises a primary coil and two secondary coils arranged such that a continuous signal produced in the secondary coils is dependent upon a continuous signal generated in the primary coil and upon the relative position of an electrically-conductive portion in relation to the primary coil and the secondary coils.

A problem with an LVDT is its relative cost.

One way of overcoming this problem is to use a potentiometer. However, the wiper contact of such a device and/or the coil thereof can become worn relatively quickly.

A first aspect of the present invention seeks to obviate one or more of the foregoing disadvantages.

Accordingly, the first aspect of the present

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invention is directed to control apparatus having the construction set out in the opening paragraph of the present specification, in which the induction device is a pulse induction device, comprising coil means having an 5 elongate electrically-conductive portion which is coiled, electrical pulse generating means connected to the coil means to deliver electrical pulses thereto, and measuring means also connected to the coil means to measure the voltage or other electrical parameter across the coil at 10 a predetermined time interval after each pulse.

The pulse induction device may comprise at least two such coiled portions which are spaced apart from one another or which diverge from one another, the portions defining a volume with the coiled portions surrounding 15 that volume, and the latter extending between those portions, the target portion and/or the coiled portions being movable whilst the target portion remains within that volume, the electrical pulse generating means being connected to both the said at least two coiled portions 20 to deliver electrical pulses thereto, and the measuring means being connected to both the said at least two coiled portions to provide a measure of the voltage or other electrical parameter across the coiled portions, and thus to provide a signal indicative of an attribute 25 of the position of the target portion within the said volume relative to the coiled portions.

The target portion may be movable. It may be fixed relative to an accelerator pedal, with the control

apparatus comprising an engine, and the control means comprising a device for varying the speed of the engine in dependence upon the signal it receives from the pulse induction device.

5       According to a second aspect of the present invention, there is provided a position sensor comprising at least two elongate electrically-conductive portions which are coiled and which are spaced apart from one another or which diverge from one another, these portions  
10 defining a volume with the coiled portions surrounding that volume and the latter extending between those portions, electrical pulse generating means connected to the coiled portions to deliver electrical pulses thereto, and measuring means also connected to the coiled portions  
15 to provide a measure of the voltage or other electrical parameter across the coiled portions, and thus to provide a signal indicative of an attribute of the position of an electrically-conductive target portion within the said volume relative to the coiled portions when the sensor is  
20 in use.

The at least two coiled portions may be spaced apart portions of a single coil, which is preferably elongate along its axis of winding or alternatively transversely of its axis of winding.

25       Alternatively, the said two coiled portions may be independently energisable, and the electrical pulse generating means may be such as to apply pulses to the two coiled portions alternately in such a manner that

there is no pulse delivered to one of the coils when the other is being energised, and vice versa, and, in such a manner that there is a delay period between each pulse to enable the voltage or other parameter across each coiled 5 portion to be measured without interference from the other coiled portion.

Preferably, each coiled portion is in the shape of a right-angled quadrilateral.

Preferably, respective parts of the two coiled 10 portions are adjacent or contiguous, and preferably the two coiled portions are set at an angle in the range from 50° to 170° to one another, preferably in the range from 95° to 150°, most preferably about 100°. This provides the benefit of an output signal from the induction device 15 being substantially linear with respect to a relative displacement of the said electrically-conductive target portion in a direction which is transverse of the said contiguous sides.

It is possible to thereby obtain a range of movement 20 with a linear response say for the target portion which is four times that for a single coil arrangement, whilst the coil arrangement might be no more than one and a half times as large.

The two coil format permits a compact sensor to be 25 constructed, and in particular reduces the size of the coils. This is highly beneficial in avoiding significant influence from the materials surrounding the sensor in use, for example mounting brackets and structural metal

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work. The coils cannot inherently distinguish between an intended target and any other conductive material within range, but small coils diminish this range.

Further, the two coil format provides cancellation 5 of such interfering effects where both coils are being affected. Complete cancellation is obtained if such interfering effects are equal in each coil.

The combined effect of small coils and the tendency to cancel interference effects typically permits an 10 unshielded dual coil sensor to be mounted directly to steel structures with minimal constraints.

Coils are a form of antenna, and keeping the coils small substantially reduces the reception of electromagnetic interference.

15 The cancellation effect also permits the incorporation of close fitting metal shielding within the sensor where external interference effects (structural or electromagnetic) would otherwise be unacceptable.

Position attributes in two degrees of freedom of 20 relative movement of the target portion can be ascertained if the position sensor has two pairs of coiled portions, each pair having the features of the said at least two coiled portions, and the two pairs being arranged orthogonally in relation to one another.

25 According to a third aspect of the present invention, there is provided a position sensor comprising an elongate electrically-conductive portion which is coiled, electrical pulse generating means connected to

the coiled portion to deliver electrical pulses thereto, and measuring means also connected to the coiled portion to provide a measure of the voltage or other electrical parameter across the coiled portion, and thus to provide 5 a signal indicative of an attribute of the relative position of an electrically-conductive target portion in relation to the coiled portion, the target portion being hollow, and relative movement between the target portion and the coiled portion, with the coiled portion remaining 10 with the target portion being possible when the sensor is in use.

Such constructions are useful for instrumentation of pneumatic and hydraulic cylinders.

In each of the said first, second and third aspects 15 of the present invention, it will be appreciated that the coiled portion or portions and/or the target portion may be movable.

Examples of apparatus and position sensors made in accordance with the present invention will now be 20 described with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic representation of control apparatus embodying the present invention;

25 Figure 2 is a perspective view of parts of further apparatus embodying the present invention;

Figure 3 is an explanatory graph;

Figure 4 is a perspective view of further modified

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apparatus embodying the present invention;

Figure 5 is a further explanatory graph;

Figures 6a to 6e show, respectively, side, bottom,  
5 end, top and perspective views of part of  
a position sensor of the control apparatus  
shown in Figure 1;

Figures 7 and 8 show further explanatory graphs;

Figures 9 shows a block circuit diagram of the  
electrical circuitry for one of the coils  
10 of the part of the position sensor shown  
in Figures 6a to 6e;

Figure 10 shows a further explanatory graph;

Figure 11 shows a further circuit diagram of the  
control apparatus shown in Figure 1;

15 Figure 12 shows the circuitry of Figures 9 and 11 in  
greater detail;

Figures 13a and 13b show side and end views of an  
alternative construction to the part shown  
in Figures 6a to 6e;

20 Figures 14a to 14e show possible modifications to  
the part shown in Figures 6a to 6e,  
Figures of the same letter being of  
corresponding view;

Figure 15 shows a perspective view of further  
25 modified apparatus embodying the present  
invention;

Figure 15a shows a perspective view of a modified  
part of the apparatus shown in Figure 15;

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Figures 16 and 19 show respective further embodiments of the present invention in diagrammatic form;

Figure 17 shows a perspective view of parts of 5 further apparatus made in accordance with the present invention; and

Figures 18 and 20 to 22 show respective further perspective views of respective further embodiments of the present invention.

10 The control apparatus shown in Figure 1 comprises an accelerator pedal 10 having an electrically-conductive ferrous-metal target portion 12 physically coupled thereto, a position sensor 14 in close proximity to the electrically-conductive portion 12, and a fuel feed 15 control 16 connected to an engine 18 to vary the speed thereof.

Depression of the pedal 10 causes a linear movement of the electrically-conductive portion 12 which is detected by the position sensor 14, the output of which 20 is received by the fuel feed control means 16 which as a result increases the speed of the latter. However, there is no wear between the electrically-conductive portion 12 and the sensor 14 because there is no physical contact or connection therebetween.

25 One simple form of parts of the apparatus shown in Figure 1 is shown in Figure 2, comprising an elongate rod as the target portion 12, and a single generally square interlaced coil 14a as part of the position sensor 14.

The response of the apparatus is plotted on the vertical axis against linear axial position of the target portion 12 along the axis on the horizontal axis in Figure 3.

Figures 4 and 5 correspond respectively to Figures 2 5 and 3, but with a tapered target portion 12. The graph shows a higher degree of linearity for greater displacement.

Figures 6a to 6e show parts of the sensor 14 and their relative position in relation to the electrically-10 conductive portion 12 of a further form of the apparatus shown in Figure 1 in greater detail. Thus, the part of the sensor shown in these Figures comprises a hollow box 20 of nylon or other electrically non-conductive plastics material, moulded into the shape of an open bottomed box. 15 The box is generally elongate. A first transverse slot 22 is machined across the outside of the top of the box. In each side of the box, on the outside thereof, are machined two slanting slots 24 which extend downwardly from one end of the slot 22 to respective corners of the 20 box, with the angle between the two slots 24 being approximately 100°. Lastly, there are two end slots 26 machined across the bottoms of the end walls of the box 20.

Two windings 28 of copper filament or other 25 electrically-conductive wire are wound around the box, each winding being generally rectangular with one side of the rectangle seated in the slot 22, the opposite side of one of the windings being in one of the slots 26 and the

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opposite side of the other winding being in the other slot 26 with the other sides of the two windings seated in the slanting slots 24. Thus, the two windings 28 diverge from one another, from their sides which are 5 contiguous and which are both seated in the slot 22, with an angle of about 100° between them.

As can be seen from Figure 6e, the electrically-conductive portion 12 has an upper end received within the interior of the box 20 without touching any part of 10 that box, this end being within a volume defined by the windings 28. The windings surround that volume, and the volume extends between the windings.

Figure 7 shows output plotted against target position when the latter is composite, providing two 15 target portions which are physically fixed in position relative to one another and which are provided with respective different coil portions the outputs from which are subtracted. The different curves show different relative positions of the two target portions, one of 20 which can be seen to provide a substantially linear output for the full movement range. This is also shown in Figure 8, where the composite target is secured to an accelerator foot pedal, and the output in volts is shown as a function of rotation of the pedal in degrees.

25 The block circuit diagram shown in Figure 9 shows circuitry used in conjunction with one of the windings 28. This comprises a system clock 30 connected to deliver clock pulses to a pulse generator 32. This delivers a

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80 $\mu$ sec switching pulse to a switch 34 so that, during that time, the switch is closed and the voltage of about 5 volts is connected to one end of the winding 28, the other being earthed. Also connected across the coil are 5 voltage measuring means 36 comprising a differential amplifier 38, a switch 40 and buffer amplifier 42 connected in series with one another with an output signal 44 being taken from the output of the buffer amplifier 42, the positive input to the differential 10 amplifier being connected to the non-earthed end of the winding 28 and the negative input of the differential amplifier being connected to a point between two series connected resistors 46 and 48 constituting a feedback from the buffer amplifier 42 and connected to earth. The 15 positive connection to the differential amplifier 38 is also connected to earth by a resistor 50.

A time delay 52 is also connected to the pulse generator 32, and a pulse generator 54 generating a pulse of approximately 3 $\mu$ sec is connected to receive a signal 20 from a delay 52 and cause the switch 40 to be closed for that pulse period.

Circuitry as shown in Figure 9 is provided for each coil 28. Such circuitry is represented in Figure 11 by the box labelled 60 for one of the windings 28 and by the 25 box labelled 62 for the other winding 28. These may be connected to a common output 64, having a smoothing capacitor 66, to provide an overall output which is in effect the measure provided by one of the windings

subtracted from the other. This gives a generally linear output in proportion to the linear displacement of the electrically-conductive portion 12 within the box 20.

Thus, when the apparatus is in use, the circuitry 5 shown in Figure 9 operates for each winding 28 with the pulses being transmitted to the two windings 28 asynchronously so that when one is energised, the other is not, and vice versa, and such that there is a delay period between each pulse when neither winding is 10 energised to avoid a measurement by one of the windings interfering with that of the other.

Considering the operation of the circuitry shown in Figure 9 for one of the windings 28, the system clock 30 causes the pulse generator 32 to close the switch 34 for 15 a period of approximately 80 $\mu$ sec. This energises the winding 28 for that period such that the voltage across the winding has a step function as shown in the graph in Figure 10. When this pulse ends at time  $t_0$  in Figure 10, the self-induction of the winding 28 causes the voltage 20 across it to fall sharply to a negative value of a magnitude well in excess of the 5 volts it had initially, whereafter at time  $t_1$  it starts to rise again and to reach zero value at about time  $t_2$  following an exponential curve C1 between time  $t_1$  and  $t_2$ . However, 25 with the presence of the electrically-conductive portion 12, it follows the broken curve C2, in which the decay of a negative voltage across the winding 28 is slowed down so that the voltage does not come to zero value again

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until about time  $t_3$ , well after time  $t_2$ . The actual measure of this decay influence is measured by that part of the circuitry shown in the box 36 of Figure 3. Thus, the switch 40 receives the pulse which closes it for 5 about  $3\mu\text{sec}$ , about  $10\mu\text{sec}$  after the winding 28 was de-energised (by which time the excitation energy has completely died away). This therefore provides a measure of the voltage across the winding 28 at time  $t_4$ , about  $20\mu\text{sec}$  after time  $t_0$  and lasting for about a period of 10  $3\mu\text{sec}$ .

The signal at the output 54 is delivered to the fuel feed control 16 shown in Figure 1, which in turn varies the speed of the engine 18 substantially linearly with respect to displacement of the accelerator pedal 10.

15 Figure 12 shows the circuitry of Figures 9 and 11 in greater detail, with corresponding parts of the circuitry in the Figures bearing the same reference numerals, save that where a part of the circuitry in Figure 12 relates to one of the windings 28, it has the suffix a, and where 20 a part of the circuitry in Figure 12 relates to the other winding 28, it has the suffix b.

In the modification of the position sensor shown in Figures 13a and 13b, the box 20 has been replaced by a hollow cylinder 70, with spacers 72 and a single elongate 25 coil 74 wound around the cylinder 70 with suitable slots (not shown) being formed in the spacers 72 to enable the winding to be continuous along the length of the cylinder 70. In this case, the movable electrically-conductive

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portion 12 (not shown in Figures 13a and 13b) would extend into the interior of the cylinder 70, without touching it, and would move in its longitudinal direction.

5        The modification to the position sensor shown in Figures 14a to 14e, comprises an increase in the width of the box 20, and the provision of two pairs of windings, each pair being wound in substantially the same fashion as in the two windings of the position sensor part shown  
10      in Figures 6a to 6e, and each pair being orthogonally arranged to the other pair. The reference numerals used in Figures 14a to 14e correspond to those used in Figures 6a to 6e. It will be appreciated that with such a construction, the position of the electrically-conductive  
15      portion 12 can be determined with respect to two degrees of freedom, so that it is possible to determine the position of the electrically-conductive portion 12 both along the length of the box 20 and also across its width. One such application for such a position sensor is to  
20      determine both the relative position along two orthogonal axes of a joystick, the outputs from the position sensor being used to position a tool and/or a machine tool table in both of two orthogonal axes, or to vary the speed of movement of the tool and/or machine tool table in these  
25      directions. In another such application, such a joystick provided with such a position sensor could be used to control a radio-controlled vehicle or toy.

Numerous variations and modifications to the

illustrated embodiments may occur to the reader without taking the result outside the scope of the present invention. For example, the box 20 with the coils 28 may be enclosed in an aluminium or copper casing to minimise 5 the effect of external fields whilst still enabling useful measurements to be made.

Further variations and modifications will now be described with reference to Figures 15 to 22.

The modified apparatus shown in Figure 15 has coiled 10 portions 14a, a main one of which is elongate transversely of its winding axis and two end coil portions overlapping the ends of the main elongate coiled portion, the latter being movable into and out of a tubular target portion 12. The latter may be modified so 15 that it has an inverted U-shape as shown in Figure 15a.

In the modified apparatus of Figure 16, the coil 14a is also elongate and the target portion 12 is tubular, being a hollow piston rod of a piston and cylinder arrangement, so that the apparatus of which the coil and 20 target portions are parts determines the position of the piston rod of this arrangement.

Figure 17 shows a possible construction for the coil 14a as two coil portions spaced apart, having a common winding axis, and being electrically connected in series 25 with one another. These coils allow for a short overall construction.

Figure 18 shows a construction having two coils 14a which are spaced apart, having a common winding axis, but

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being connected separately to a position sensor (not shown in Figure 18), so as to provide signals which are subtracted from one another to give a substantially linear response, that being further enhanced by the 5 target portion 12, which is composite and which has two tapered ends each movable into and out of the volumes surrounded respectively by the coil portions.

In the apparatus of which a part is shown in Figure 19, the coils 14a are arranged as shown in Figure 18, but 10 the target portion comprises a steel ball 12, which is free to roll on a part spherical dish 90, so that the apparatus is able to measure tilt, and could comprise a tilt switch. This arrangement may be enclosed and within oil for lubrication and damping.

15 In the arrangement of Figure 20, the coils 14a are placed alongside one another with the respective axes of winding parallel with one another, and the target portion 12 is again composite, comprising a yoke with a tapered end on the axis of one of the coils 14a and another 20 tapered end on the axis of the other of the coils 14a, the yoke being arranged to be movable linearly along a direction parallel to the coil axes, the ends of the target portion 12 extending in opposite directions so that as one end approaches its coil 14a, the other leaves 25 its coil 14a whilst travelling in the same direction, and vice versa. The same effect is obtainable with a motion of the yoke about an axis which is displaced from the coils and which is parallel to a line passing through the

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centres of the coils 14a.

In the modification shown in Figure 21, the yoke is generally semi-circular, with its ends generally at the respective centres of the coils 14a, possible movement of 5 the yoke being a rocking motion about the centre of the circle on which it lies.

In the construction shown in Figure 22, the target is hollow, comprising two generally trapezoidal sides 121 connected above by a bridging portion 122. This is 10 linearly movable to receive, to an increasing or decreasing extent, two coils arranged as in Figures 20 and 21, the sides 121 being parallel to the coils 14a.

Each of the coils 14a in the arrangements shown in Figures 18 to 22 may comprise the composite coil 15 construction shown in Figure 17.

The portions of a composite target could be separate.

The targets may be made of steel, aluminium, brass or other electrically-conductive metal alloy or other 20 electrically-conductive material.

The electrically-conductive material of the target is advantageously magnetically permeable, as is steel for example.

**Claims:**

1. Control apparatus comprising at least one electrically-conductive target portion, and a position sensor in the form of an induction device arranged in proximity with the said at least one electrically-conductive target portion to provide a signal indicative of an attribute of the position of that portion relative to a portion of the induction device, and control means connected to receive such a signal from the induction device and to respond in dependence upon that signal, in which the induction device is a pulse induction device, comprising coil means having an elongate electrically-conductive portion which is coiled, electrical pulse generating means connected to the coil means to deliver electrical pulses thereto, and measuring means also connected to the coil means to measure the voltage or other electrical parameter across the coil at a predetermined time interval after each pulse.
2. Control apparatus according to claim 1, in which the pulse induction device comprises at least two such coiled portions which are spaced apart from one another or which diverge from one another, the portions defining a volume with the coiled portions surrounding that volume, the latter extending between those portions, the target portion and/or the coiled portions being movable whilst the target portion remains within that volume, the electrical pulse generating means being connected to both the said at least two coiled portions to deliver

electrical pulses thereto, and the measuring means being connected to both the said at least two coiled portions to provide a measure of the voltage or other electrical parameter across the coiled portions and thus to provide 5 a signal indicative of an attribute of the position of the target portion within the said volume relative to the coiled portions.

3. Control apparatus according to claim 1 or claim 2, in which the target portion is movable.

10 4. Control apparatus according to claim 3, in which the apparatus comprises an engine, the movable target portion is fixed relative to an accelerator pedal, and the control means comprises a device for varying the speed of the engine in dependence upon the signal it receives from 15 the pulse induction device.

5. A position sensor comprising at least two elongate electrically-conductive portions which are coiled and which are spaced apart from one another or which diverge from one another, these portions defining a volume with 20 the coiled portions surrounding that volume and the latter extending between those portions, electrical pulse generating means connected to the coiled portions to deliver electrical pulses thereto, and measuring means also connected to the coiled portions to provide a 25 measure of the voltage or other electrical parameter across the coiled portions, and thus to provide a signal indicative of an attribute of the position of an electrically-conductive target portion within the said

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volume relative to the coiled portions when the sensor is in use.

6. Control apparatus according to claim 2, or to claim 3 or 4 read as appended to claim 2, or a position sensor according to claim 5, in which the at least two coiled portions are spaced apart portions of a single coil.
7. Control apparatus according to claim 6, in which the said single coil is elongate along its axis of winding.
- 10 8. Control apparatus according to claim 2, or claim 3 or 4 read as appended to claim 2, or a position sensor according to claim 5, in which the two coiled portions are independently energisable, and the electrical pulse generating means are such as to apply pulses to the two 15 coiled portions alternately in such a manner that there is no pulse delivered to one of the coils when the other is being energised, and vice versa, and, in such a manner that there is a delay period between each pulse to enable the voltage or other electrical parameter across each 20 coiled portion to be measured without interference from the other coiled portion.
9. Control apparatus or a position sensor according to claim 8, in which each coiled portion is in the shape of a right-angled quadrilateral.
- 25 10. Control apparatus or a position sensor according to claim 8 or claim 9, in which respective parts of the two coiled portions are contiguous.
11. Control apparatus or a position sensor according to

any one of claims 8 to 10, in which the two coiled portions are set at an angle to one another.

12. Control apparatus or a position sensor according to claim 11, in which the said angle is in the range from 5 50° to 170°.

13. Control apparatus or a position sensor according to claim 12, in which the said angle is in the range from 95° to 150°.

14. Control apparatus or a position sensor according to 10 claim 13, in which the said angle is about 100°.

15. Control apparatus according to any one of claims 2 and 8 to 14, or claim 3 or 4 read as appended to claim 2, or a position sensor according to claim 5 or any one of claims 8 to 14, in which the position sensor has two 15 pairs of coiled portions, each pair having the features of the said at least two coiled portions, and the two pairs being arranged orthogonally in relation to one another, thereby to enable position attributes in two degrees of freedom of movement of the movable control 20 member to be ascertained.

16. Control apparatus or a position sensor according to any preceding claim, in which an electrically-conductive casing surrounds the or each coiled portion and the electrically-conductive portion which moves when the 25 apparatus or sensor is in use.

17. A position sensor comprising an elongate electrically-conductive portion which is coiled, electrical pulse generating means connected to the coiled

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portion to deliver electrical pulses thereto, and measuring means also connected to the coiled portion to provide a measure of the voltage or other electrical parameter across the coiled portion, and thus to provide 5 a signal indicative of an attribute of the relative position of an electrically-conductive target portion in relation to the coiled portion, the target portion being hollow, and relative movement between the target portion and the coiled portion, with the coiled portion remaining 10 with the target portion being possible when the sensor is in use.

18. Control apparatus or a position sensor according to any preceding claim, in which the electrically-conductive target position comprises magnetically permeable 15 material.

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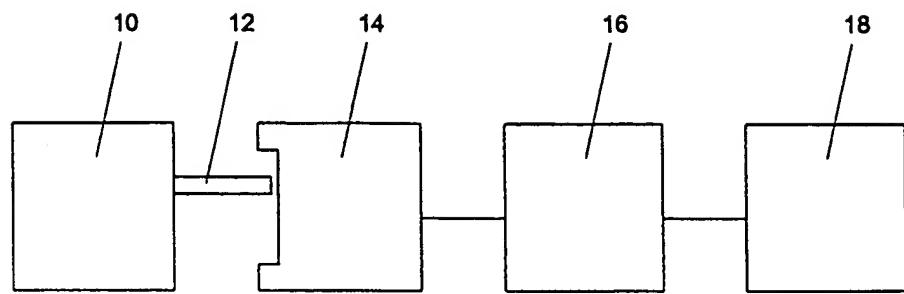


Figure 1.

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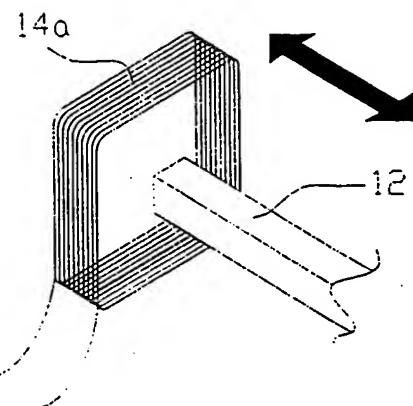


FIG 2

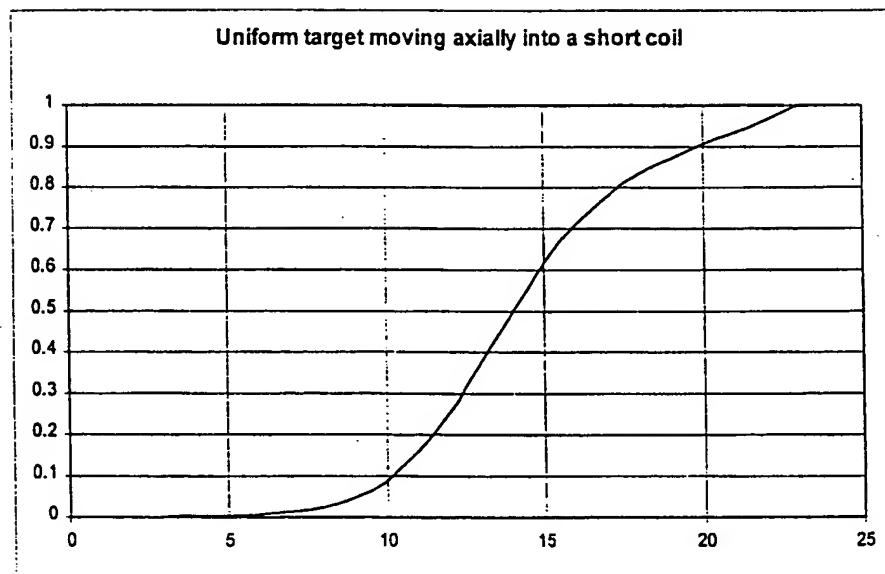


FIG 3

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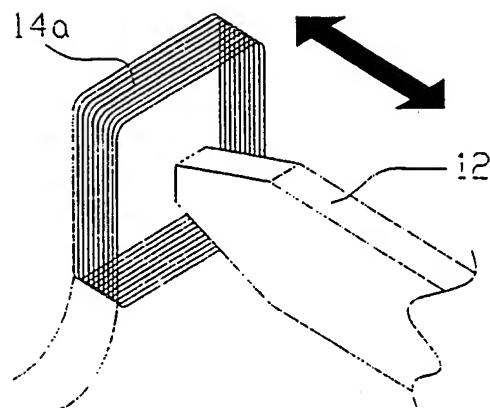


FIG 4

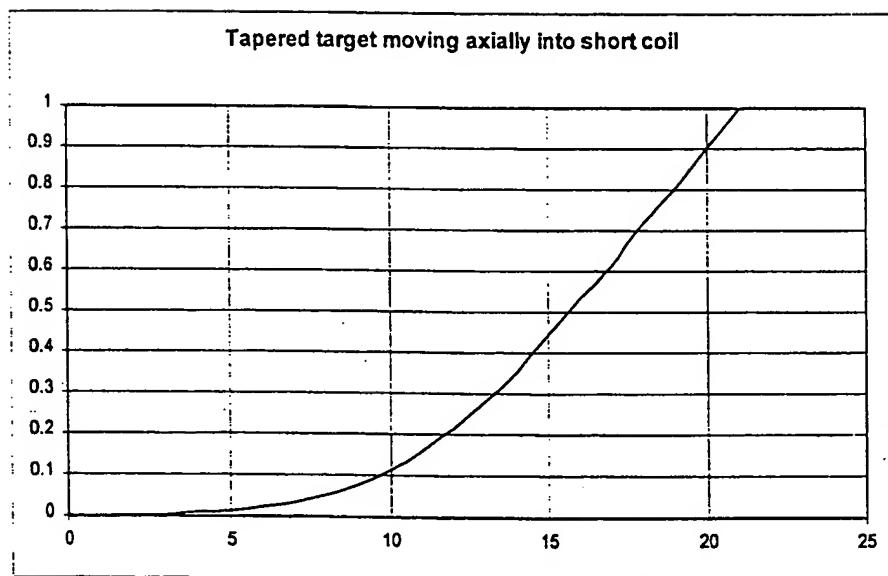


FIG 5

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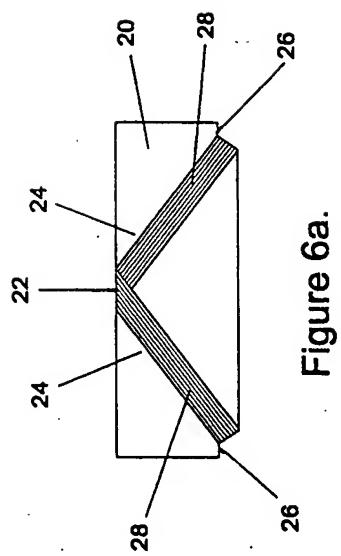


Figure 6a.

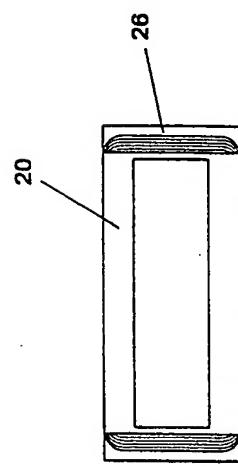


Figure 6b.

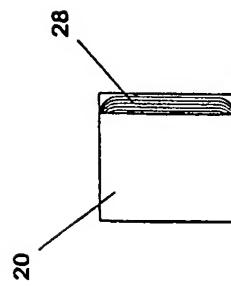


Figure 6c.

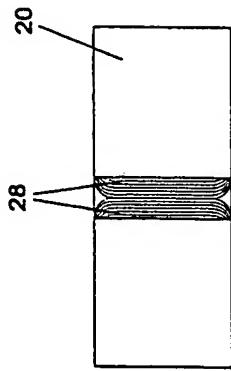


Figure 6d.

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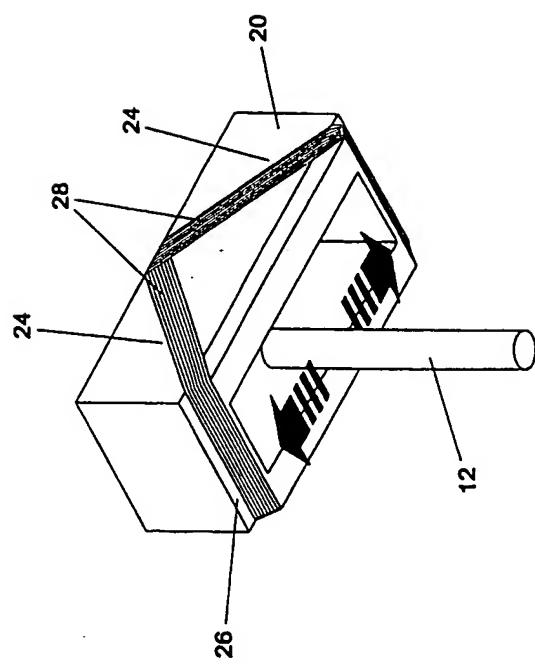


Figure 6e.

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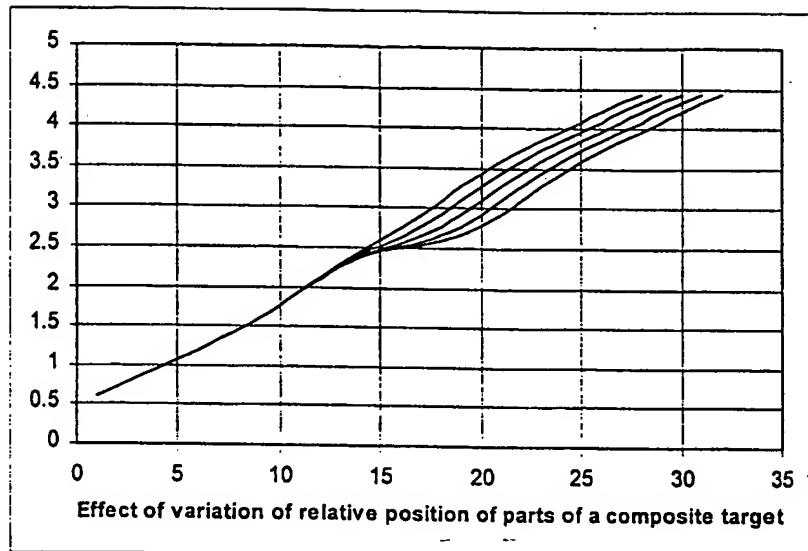


FIG 7

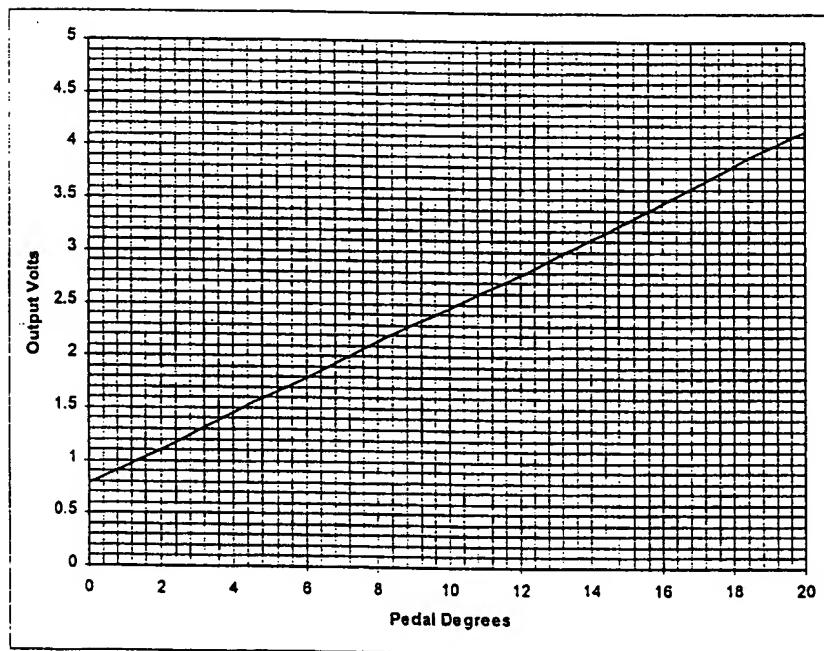


FIG 8

S U B S T I T U T E S H E E T (R U L E 26)

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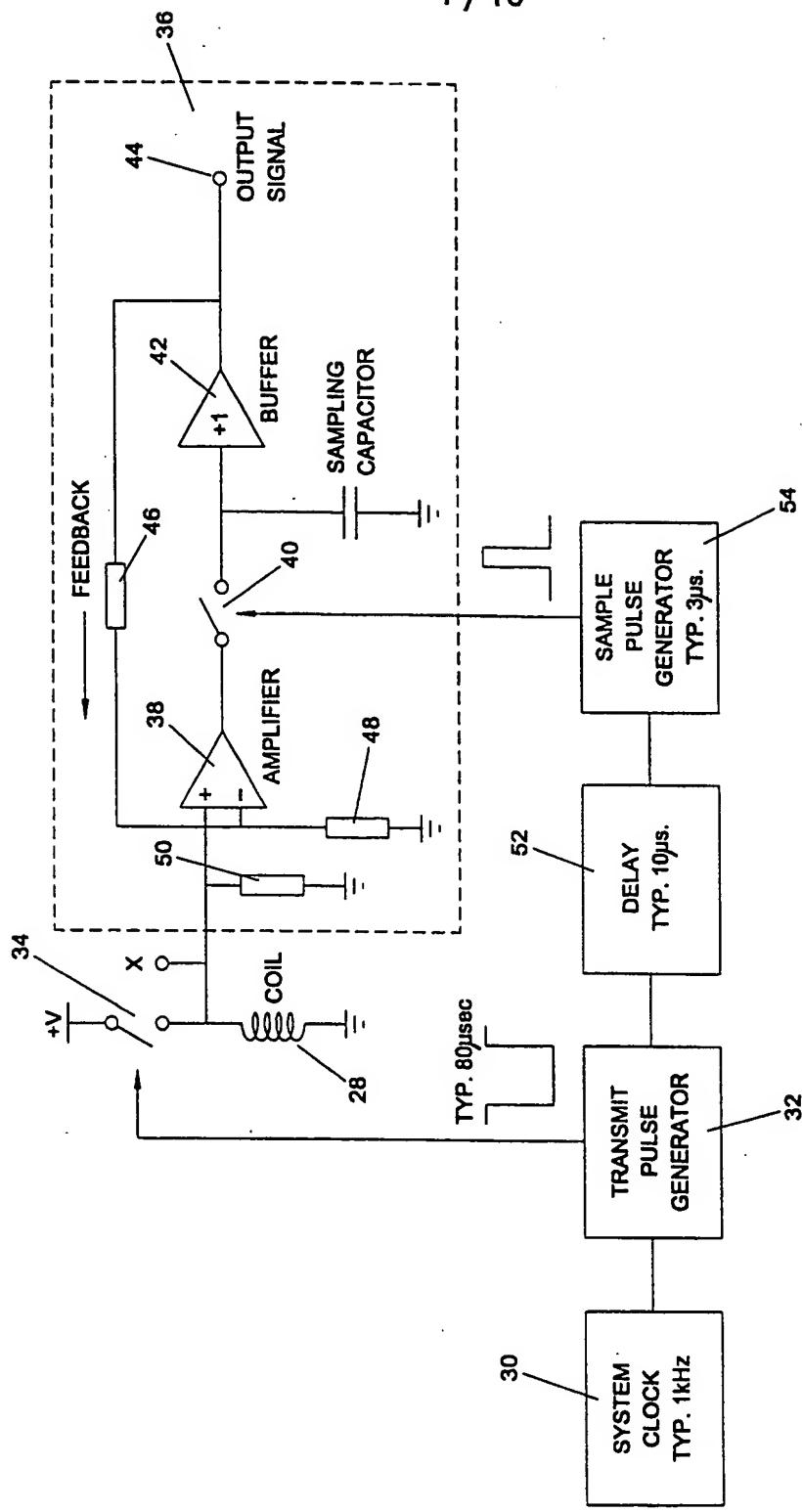


Figure 9.

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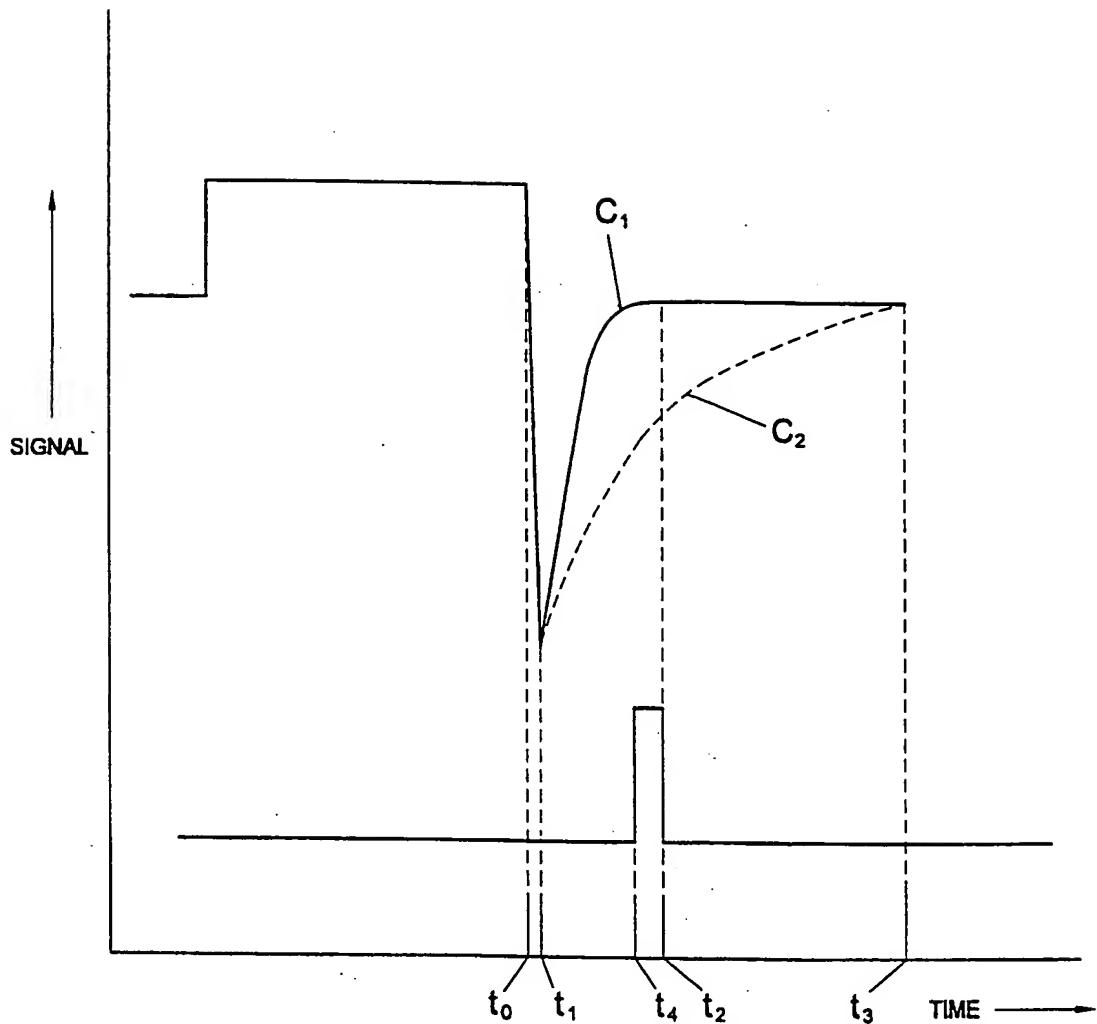


Figure 10.

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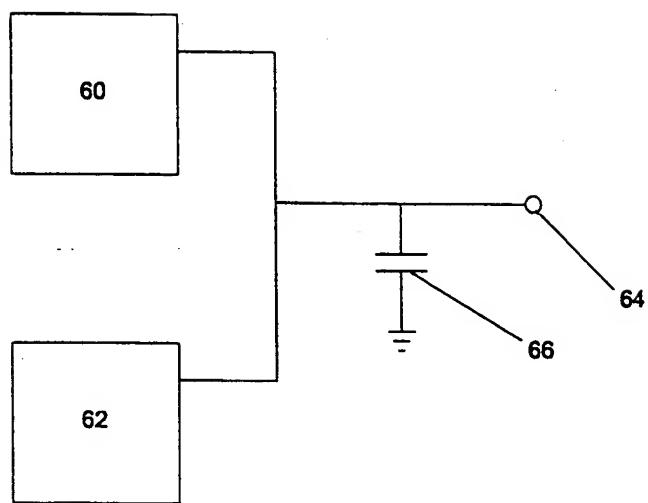


Figure 11.

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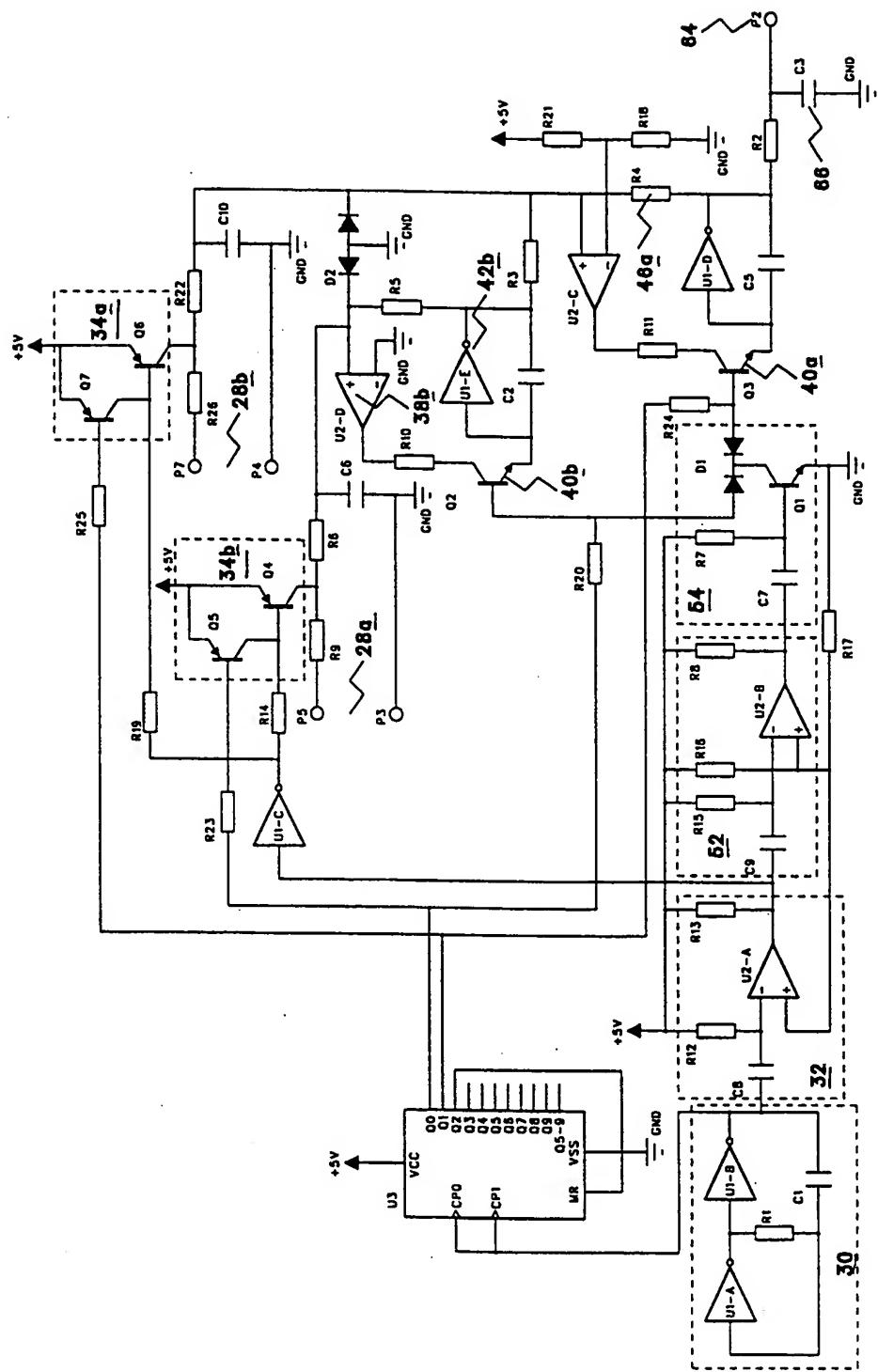


FIG. 12

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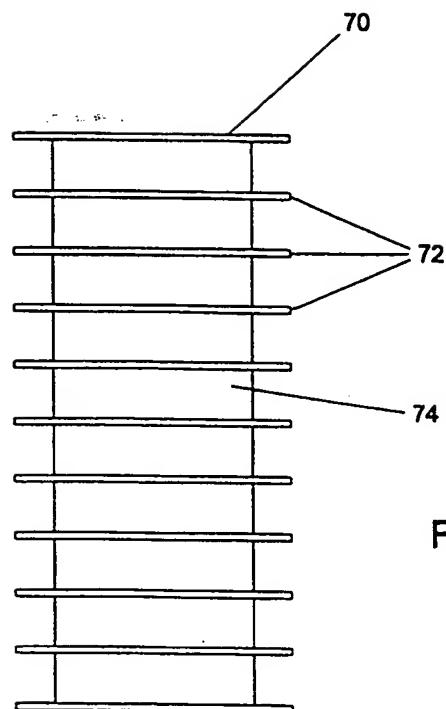


Figure 13a.

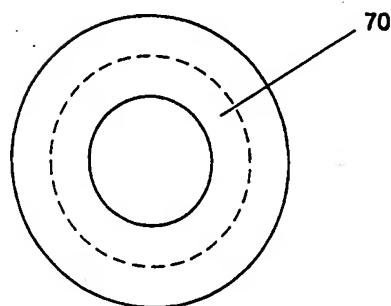


Figure 13b.

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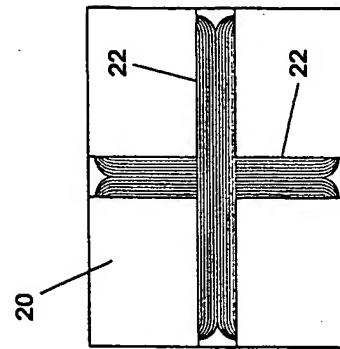


Figure 14d.

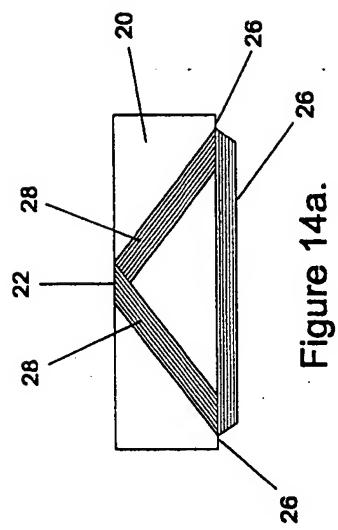


Figure 14a.

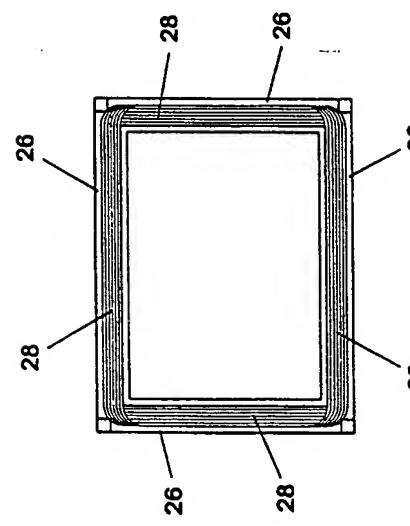


Figure 14b.

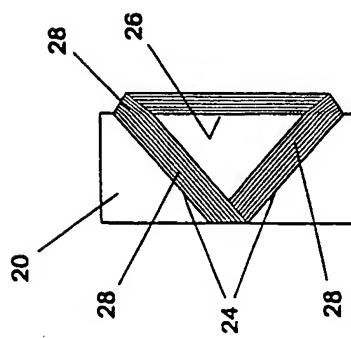


Figure 14c.

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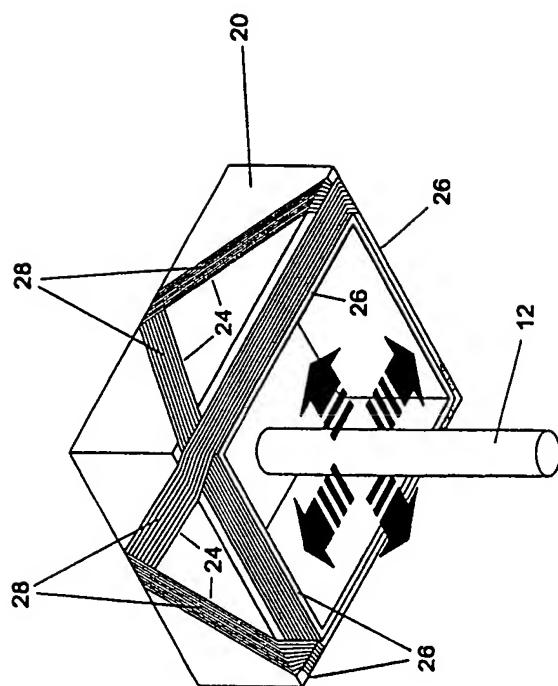


Figure 14e.

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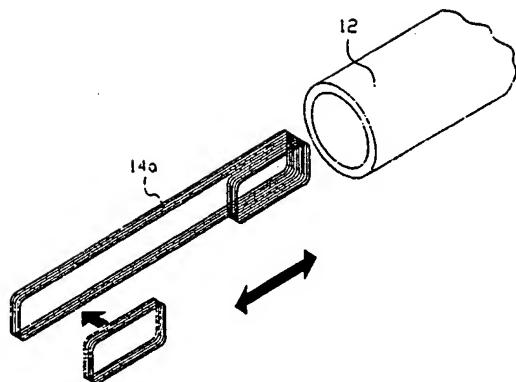


FIG15

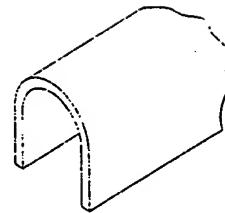


FIG15a

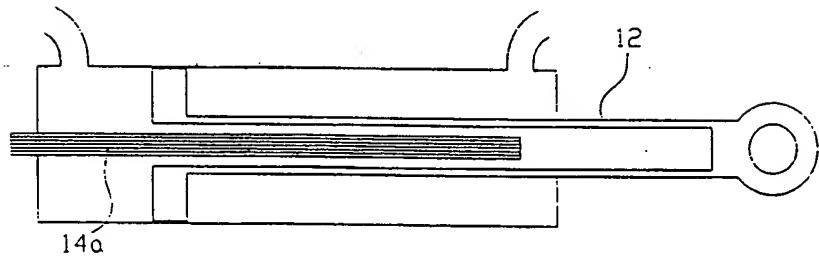


FIG16

S U B S T I T U T E S H E E T (R U L E 2 6)

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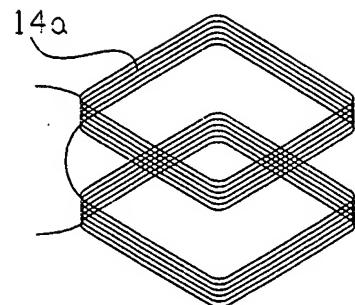


FIG17

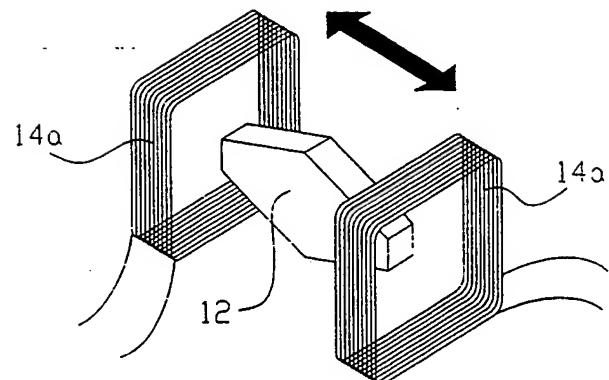


FIG18

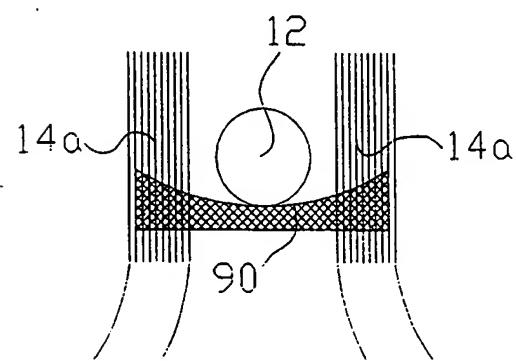


FIG19

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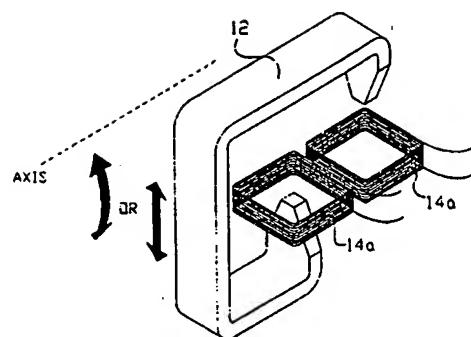


FIG 20

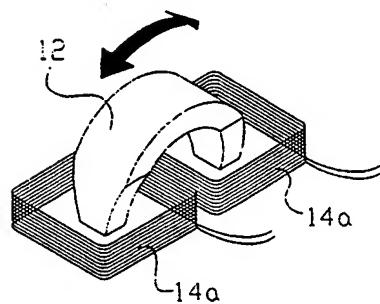
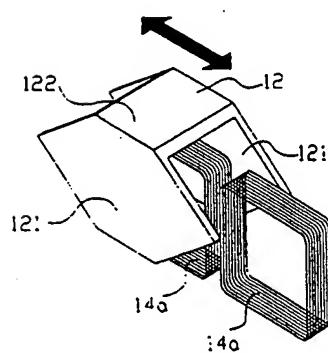


FIG 21

FIG 22  
SUBSTITUTE SHEET (RULE 26)

# INTERNATIONAL SEARCH REPORT

Inte onal Application No  
PCT/GB 99/02656

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 7 G01D5/20

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 G01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 712 563 A (OHTA SUSUMU ET AL) 27 January 1998 (1998-01-27) column 5, line 38 -column 8, line 35; figures 1-8	1,3,5
Y	---	16,17
A	---	4,6-15
X	GB 2 207 270 A (SORENSEN THOMAS PATRICK;BOYLAN MARTIN GERARD) 25 January 1989 (1989-01-25) page 9, paragraph 4 -page 11, paragraph 2; figure 5	5,6,8-12
Y	---	7
Y	US 5 453 685 A (GOULD LARRIE A ET AL) 26 September 1995 (1995-09-26) column 3, line 27 -column 4, line 48; figures 1,2	7,16,17
	-----	

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority, claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Date of the actual completion of the international search

18 November 1999

Date of mailing of the International search report

25/11/1999

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Authorized officer

Chapple, I

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

Inte onal Application No

PCT/GB 99/02656

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 5712563	A 27-01-1998	JP 7333080	A	22-12-1995
		JP 7332910	A	22-12-1995
		DE 19521531	A	14-12-1995
		GB 2290384	A,B	20-12-1995
GB 2207270	A 25-01-1989	NONE		
US 5453685	A 26-09-1995	NONE		